DETERMINATION OF THE EFFECTS OF IRON AND OXYGEN CONTENTS ON THE MECHANICAL PROPERTIES OF TITANIUM -5Al-2.5 Sn ALLOY SHEET AT LIQUID HYDROGEN TEMPERATURE (-423°F)

MRG-262

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GENERAL DYNAMICS/CONVAIR

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SUBJECT: "Determination of the Effects of Iron and Oxygen Contents on the Mechanical Properties of Titanium-5Al-2.5 Sn Alloy Sheet at Liquid Hydrogen Temperature (-423°F)."

ABSTRACT: The purpose of this investigation was to determine the effects of two common impurities, iron and oxygen, on the mechanical properties, particularly the toughness, of titanium-5Al-2.5 Sn alloy sheet at liquid hydrogen temperature (-423°F.) Yield and tensile strengths, elongations, notched (K_t=6.3) tensile strengths and notched/unnotched tensile ratios were obtained on three experimental heats of Ti-5Al-2.5 Sn alloy. The three heats represented high iron + low oxygen, medium iron + high oxygen, and low iron + low oxygen combinations. The data show increased strengths and decreased toughness for the high iron and the high oxygen heats. Even in small amounts iron causes the deleterious formation of some beta phase in the alpha structure of this alloy. Photomicrographs show that the high iron heat has the most beta phase and the low oxygen + low iron heat has the least beta phase present in the microstructure. It is recommended that further testing using alloys of additional iron + oxygen combinations be conducted to substantiate these results. However, based on present data, it appears that the chemical composition of the titanium 5Al-2.5 Sn alloy should be held to a maximum of 0.12% oxygen and 0.25% iron in order to retain adequate toughness for structural applications at liquid hydrogen temperatures (-423°F).

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SUBJECT: Determination of the Effects of Iron and Oxygen Contents on the Mechanical Properties of Titanium-5Al-2.5 Sn Alloy Sheet at Liquid Hydrogen Temperature (-423°F).

INTRODUCTION:

The mechanical properties of a large number of titanium alloys have been determined at cryogenic temperatures. Report MRG-189, dated 14 October 1960, gives the mechanical properties of nine titanium alloys from 78° to -423°F. Of these alloys, only one, the titanium -5Al-2.5 Sn material, retains sufficient toughness for structural applications at liquid hydrogen temperature (-423°F). It has been found, however, that the toughness of this alloy, as well as of the other titanium alloys, at cryogenic temperatures is dependent upon the amount of interstitial impurities (C, O_2, N_2, H_2) contained. There were also indications that the toughness of this alloy was dependent upon its content of the substitutional impurity iron, since iron is known to be a beta phase stabilizer. The beta phase is body-centered-cubic in structure and is inherently brittle at cryogenic temperatures.

Based on the tests conducted previously using several heats of Ti-5Al-2.5 Sn the current GD/A specification, 0-71010, Revision A, 12 June 1961, sets the following limits for these two impurities: oxygen = 0.12% maximum, and iron = 0.25% maximum.

The following investigation was made to determine the effects of various iron and oxygen contents on the tensile properties and toughness of the titanium - 5Al-2.5 Sn alloy at -423°F.

Materials

Three experimental heats of the titanium -5Al-2.5 Sn alloy were tested. The three heats represented low iron + low oxygen, medium iron + high oxygen, and high iron + low oxygen combinations. The material was tested in the as-received (mill annealed) condition. Heat numbers, gauge, and chemical analyses are given in Table 1. The material was supplied by Titanium Metals Corporation of America.

Procedure

Because of limitation of material only longitudinal (parallel to the direction of rolling) specimens were tested. Blanks for tensile and notched tensile specimens, 9" x 1½", were identified and sheared. Smooth (EMG-D-1) and notched (MRG-D-10, Notch "A") tensile specimens were machined. Notched tensile specimens were inspected and measured with an optical comparator. The specimens were tested at -423°F by submergence in a bath of liquid hydrogen. Strain measurements were made by a "cryo-extensometer" and a continuous stress-strain recorder. Strain rates were maintained at 0.001"/"/min. until 0.2% offset yield and then 0.15"/min. until fracture. Total elongations were determined over a 2" gauge length made by scribe marks with a precision block and read at 10x magnification. The 35,000# Tinius-Olsen universal testing machine, strain recorder, strain pacer, and "cryo-extensometer" are periodically calibrated by the Standards Laboratory.

Results and Discussion

The mechanical properties obtained in this investigation are given in Table 2. Photomicrographs showing typical microstructures of the three heats are given in Figure 1. As may be seen in Table 2 yield and tensile strengths increase proportionately with an increase in iron and oxygen content, just as would be expected. The ductility as measured by elongation decreases with greater iron and oxygen contents. Toughness, as measured by notched/unnotched tensile ratios, is good for the low iron-low oxygen heat (notched/unnotched ratio of 1.00) but quite poor for the high iron and the high oxygen heats (ratios of 0.71 and 0.65 respectively). The notched/unnotched ratio of the high iron heat (V-1866) is 0.65 if the tensile data on the specimen which failed in the extensometer clamp is discarded. Previous data have indicated that the toughness of the titanium-5Al-2.5 Sn alloy is dependent upon the oxygen content; however this investigation is the first attempt to evaluate the effects of iron on the tensile properties and toughness of the Ti-5Al-2.5 Sn alloy at -423°F. The photomicrographs given in Figure 1 show that the high-iron heat contains the most beta phase of the three heats. Likewise the medium-iron heat contains less beta and the low iron heat contains the least amount of the beta phase. It is believed that the decreased toughness of the high-iron heat at -423°F is due to the larger amount of the beta phase present in the microstructure.

RECOMMENDATIONS:

It is recommended that more tests be made in order to substantiate the data obtained in this investigation. Larger quantities of these three heats of material, cold-rolled to approximately 0.020" gauge and annealed, are to be supplied by TMCA.

In addition, it will be important to test one or more heats of this alloy having combinations of low oxygen + medium iron impurities, such as the 0.12% oxygen + 0.25% iron combination permitted by our current specification. A small amount of iron in the alloy improves its rolling characteristics; hence, is desirable from the viewpoint of the mill producers. But, on the other hand, we must specify a realistic maximum iron limit that does not impair toughness of the sheet at extreme subzero service temperatures. Based upon the data obtained to date, it is recommended that the specified iron and oxygen contents of the Ti-5Al-2.5 Sn alloy be maintained at 0.25% and 0.12%, respectively. However, generation of additional test data may indicate the advisability of revising the specification.

CONCLUSIONS

1. Yield and tensile strengths of the Ti-5Al-2.5 Sn alloy sheet at -423°F increase with increase in iron and oxygen content.
2. Ductility, as measured by elongation, is less for the high iron and high oxygen bearing heats than for the low iron + low oxygen heat.
3. Toughness, as measured by notched tensile strengths and notched/unnotched tensile ratios, is good for the low oxygen + low iron heat, but poor for the high iron + low oxygen heat and high oxygen + medium iron heat.
4. Further tests should be made to substantiate the above results, and to determine more precisely the maximum iron content which can be tolerated in this alloy for extreme subzero temperature service.

Table 1.
Chemical Analysis of Titanium-5Al-2.5 Sn Alloys*

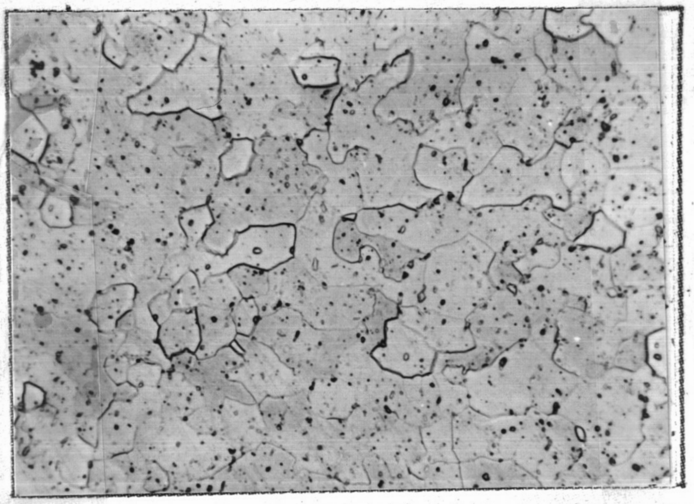
Heat No.	Gauge (in.)	Chemistry (wt.%) Al	Sn	Fe	O_2
D-1311	0.036	5.2	2.5	0.27	0.20
V-1866	0.035	5.3	2.5	0.50	0.08
V-1867	0.041	5.2	2.6	0.15	0.07

*Supplied by Titanium Metals Corporation of America

Table 2.
Mechanical Properties of Titanium-5Al-2.5 Sn Alloys

Heat No.	Test Temp. °F.	F_{ty} ksi	F_{tu} ksi	Elong. %	Notched T.S. (K_T=6.3) ksi	Notched/Unnotched Tensile Ratio
D-1311	-423	261	264	7.0	162	
"	-423	250	266	7.0	170	
"	ave.	256	265	7.0	166	0.65
V-1866	-423	225	228*	1.5*	177	
"	-423	226	276	11.0	182	
"	ave.	226	252	6.3	180	0.71
V-1867	-423	211	229	13.0	235	
	-423	-	235	15.5	231	
	ave.	211	232	14.3	233	1.00

*Failed at extensometer clamp (Premature failure).



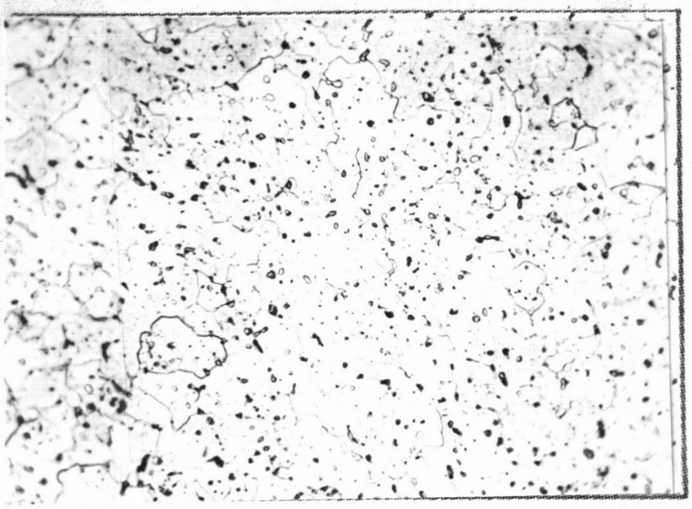
TMCA Heat D-1311

Oxygen = 0.20%

Iron = 0.27%

Magnification = 500X

Etchant: Aqueous 1%HF + 3% HNO_3



TMCA Heat V-1866

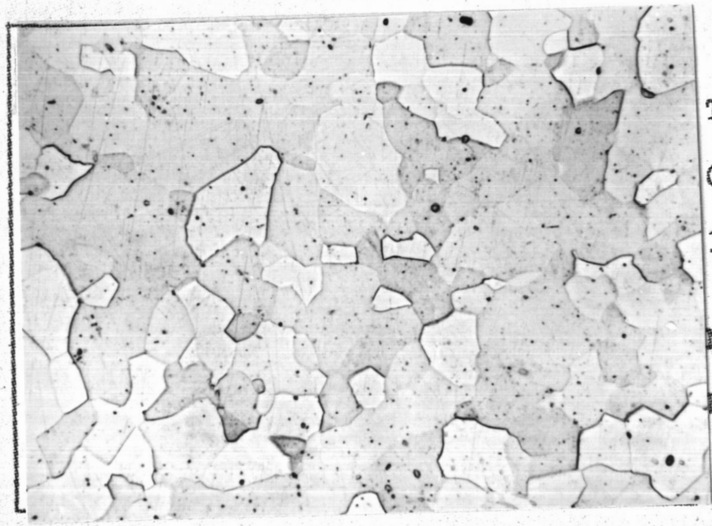
Oxygen = 0.08%

Iron = 0.50%

Magnification = 500X

Etchant: Aqueous 1% HF + 3% HNO_3

Fig. 1. Microstructures of three experimental heats of Ti-5Al-2.5 Sn which show that the amount of beta phase particles in the alpha matrix is directly related to the iron content.



TMCA Heat V-1867

Oxygen = 0.07%

Iron = 0.15%

Magnification = 500X

Etchant: Aqueous 1% HF + 3% HNO_3

Fig. 1. (cont.) Microstructures of three experimental heats of Ti-5Al-2.5 Sn which show that the amount of beta phase particles in the alpha matrix is directly related to the iron content.